

## Low Moment Measurements with a Vibrating Sample Magnetometer

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### Introduction

The development of ultrathin magnetic films and multilayers for magnetic recording applications continues unabated. Additionally, impetus for the research and development of nanoscale magnetic materials for biomagnetic, MEMS, and NEMS applications is increasing. Improvements in magnetometer sensitivity have been required to allow for measurement of the vanishingly small magnetic signals arising from these materials.

Although the most sensitive magnetometers, SQUIDS and force-based techniques (e.g., AGM), allow for such measurements with RMS noise levels on the  $10^{-8}$  emu level, their application utility is somewhat limited. SQUIDS require liquid helium even for ambient or high temperature operation, and the data acquisition process is inherently slow, since superconducting magnets are used for field generation. Force-based techniques, although fast, are generally limited to small samples (typically less than 2 to 3 mm), which renders sample handling (e.g., loading/unloading) difficult and cumbersome, and these methodologies are generally characterized by relatively poor reproducibility and limited variable temperature capability. Both techniques lack the robustness and ease-of-use that are often desirable attributes for routine, high throughput magnetic measurement applications.

Although less sensitive than these techniques, a VSM affords the opportunity for accurate and reproducible measurements at low, high, and ambient temperatures. It can accommodate materials of various sizes and in any form (i.e., solids, films, crystals, and liquids). In addition, a VSM is a robust instrument that is simple to use and features fast data acquisition cycles, rendering it ideal for both magnetic research environments and magnetic metrology (e.g., ex-situ in-line metrology) applications. Further, improvements in VSM sensitivity have extended its utility into those measurement applications often reserved for SQUIDS and force techniques, i.e., low moment measurements.

This note will broadly highlight important VSM design considerations for low moment measurements, and will present low moment data recorded using the Lake Shore VSM, thus demonstrating its performance characteristics.

### Considerations for Low Moment Measurements

There are a number of pertinent issues that bear on a VSM's effectiveness for conducting magnetic measurements on low moment materials:

- 1) **Background Signals** – VSM measurements on low moment samples will often be dominated by the diamagnetic or paramagnetic contributions arising from the sample holder, and in the case of thin films, the film substrate material. Extracting the magnetic signal arising from the magnetic layer in question from these background signals requires: a) minimization of the sample holders magnetic signature, and b) a means for subtracting substrate contributions. Lake Shore has developed sample holders that are characterized by very small magnetic signals, optimal for low moment measurements. Moreover, a substrate material may be measured and subsequently subtracted from the film + substrate data yielding the magnetic signal from the magnetic layer, or a linear correction applied to the film + substrate data to analytically remove substrate contributions. Both features have been incorporated into the VSM system software.

2) Sensitivity – The sensitivity of a VSM depends on a number of factors:

- Electronic sensitivity
- Noise rejection through signal averaging
- Amplitude and frequency of mechanical drive
- Thermal noise of sensing coils
- Optimized sensing coil design for specific sample geometries
- Optimized coupling (proximity) of sensing coils to the sample under test
- Vibration isolation of the mechanical head assembly from the electromagnet and VSM sensing coils
- Minimization of environmental, mechanical, and electrical noise sources that can deleteriously affect VSM sensitivity

All of these factors have been considered in the design and development of the Lake Shore VSM. Continuous improvements have been made in the electronics and mechanical (head drive) subsystems. Sensing coil designs optimized for both large (up to 25 mm) and small (<6 mm) disk geometries have been developed. Variable-gap electromagnets that allow optimization of sensing coil coupling (proximity) to any sample geometry are used. In addition, a VSM head mounting structure is used that isolates the VSM head from the electromagnet and sensing coils, thus eliminating head vibration coupling and improving the linearity of background signals and VSM sensitivity.

When optimized for low moment measurements on small sample specimens (<6 mm) the RMS noise of the Lake Shore VSM is better than 1  $\mu\text{emu}$ , rendering it ideal for conducting magnetic measurements on ultrathin magnetic films and multilayers, as well as nanoscale magnetic materials.

### Measurement Results for Low Moment Samples

As a demonstration of performance capabilities, following are typical Lake Shore VSM low moment measurement results for several hard disk (HD) thin film samples.

Figure 1: M(H) for CoCrPtTa HD film –  
M(H) for VSM sample holder and substrate are also shown

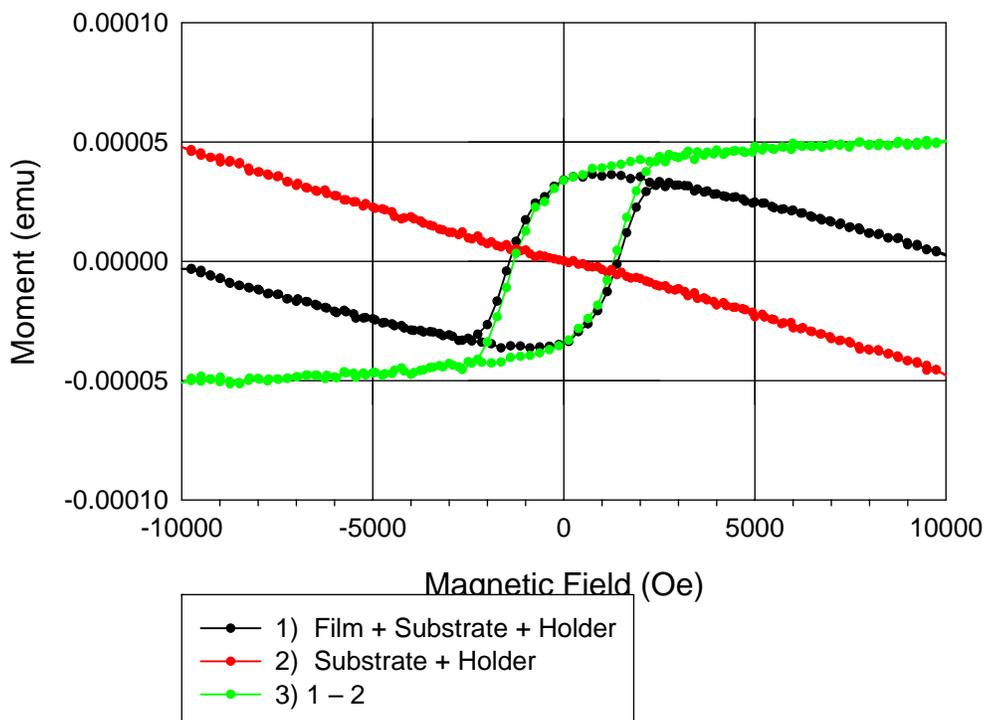
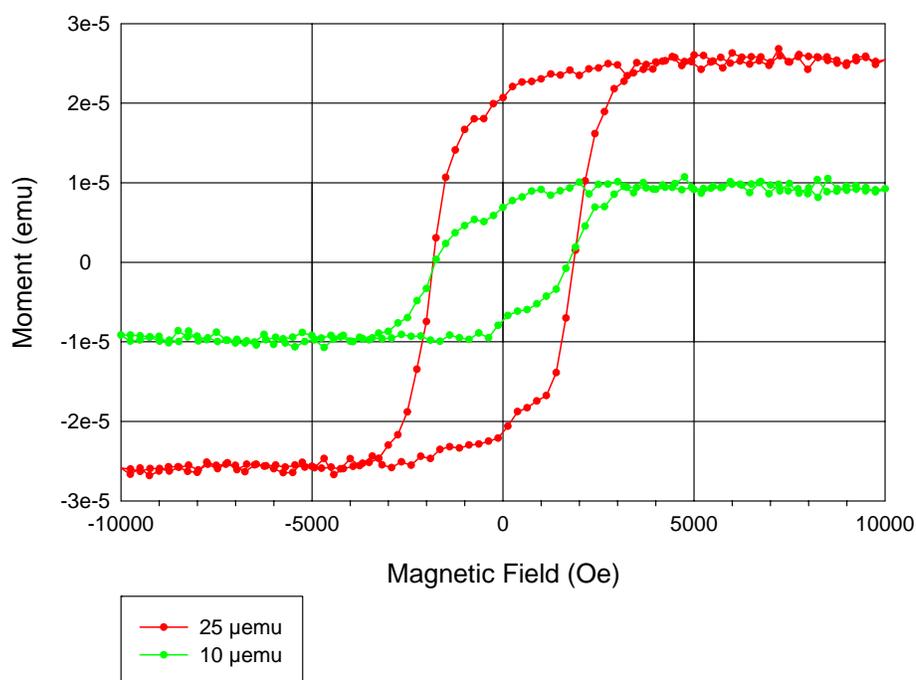


Figure 1 shows hysteresis  $M(H)$  loops for a CoCrPtTa alloy HD film sample (5 mm  $\times$  5 mm). Data were recorded at ambient room temperature and to applied fields of 10 kOe (1 T) aligned in-plane and parallel to the easy axis of magnetization. Data are presented for: 1) Film + substrate + holder, 2) substrate + holder, and 3) (1) – (2), or the  $M(H)$  loop for the magnetic film only. Note the very low background signal arising from the VSM sample holder. Even with the diamagnetic substrate, contribution the total signal is only 50  $\mu\text{emu}$  at 10 kOe. These results illustrate the importance of the background issues discussed in the previous section.

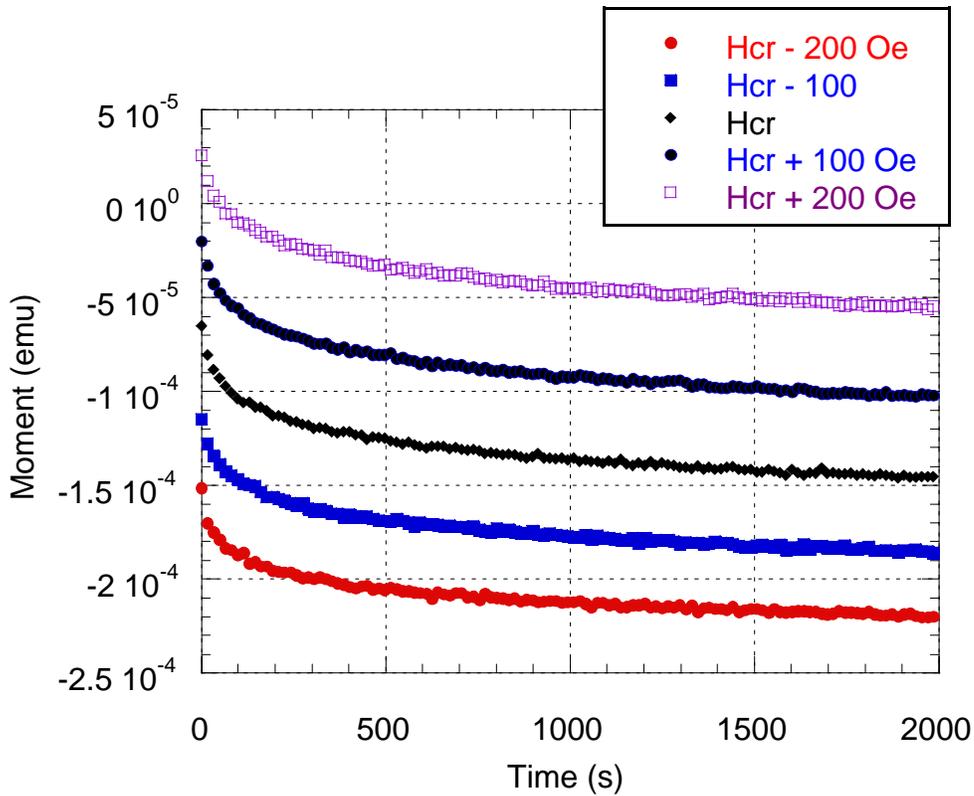
Figure 2 shows  $M(H)$  loop data for two CoCrPtX alloy HD films of saturation moment 25 and 10  $\mu\text{emu}$ , respectively. These results show the excellent signal-to-noise (SNR) or sensitivity characteristics of the Lake Shore VSM. Note that peak-to-peak data scatter is only on the few  $\mu\text{emu}$  level, consistent with an RMS noise specification of better than 1  $\mu\text{emu}$ .

Figure 2:  $M(H)$  for two low moment CoCrPtX alloy HD films



In addition to hysteresis loop measurements, a VSM allows for remanence curve measurements (IRM & DCD), temperature dependent measurements, and time dependent measurements. As film thicknesses and magnetic grain sizes decrease, the measurement of magnetization relaxation or viscosity in HD films is exceedingly important in understanding the micromagnetic interactions between magnetic grains that constitute the film, or in the case of patterned media, interactions between the magnetic bits. Figure 3 shows low moment time dependent remanent magnetization data for an HD film sample. Figures 1 through 3 demonstrate the excellent sensitivity of the Lake Shore VSM and thus its utility for measuring low moment magnetic materials.

Figure 3: Time dependent remanent magnetization data for a HD film



### Summary

The measurement of low moment magnetic materials using Vibrating Sample Magnetometry has been discussed. The relevant issues for conducting such measurements with superior SNR characteristics have been broadly highlighted, and data have been presented for low moment HD film specimens thus showing the low moment measurement capabilities of the Lake Shore VSM. As film thicknesses decrease further, and as the development of nanoscale magnetic materials progresses, further improvements in VSM sensitivity and the development of alternative magnetometry methodologies with increased sensitivity will be required. The continued evolution and improvement of existing methodologies, and the development of new magnetic measurement techniques is continuously underway at Lake Shore.